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(54) Apparatus for producing soft X-rays using a high energy beam.

(57) An apparatus for producing soft x-rays from generating plasma source which comprises a low pressure vessel, energy beam means, such as a laser beam, associated with the low pressure vessel for generating and supplying a high energy beam to an impact area inside the low pressure vessel, a liquid target, such as mercury, capable of emitting x-rays when impacted by a high energy beam target supply means associated with the low pressure vessel for supplying the liquid target material to the impact area inside the low pressure vessel, and control means coupled to the energy beam means so that the high energy beam impacts the liquid material target in the impact area of the low pressure vessel.

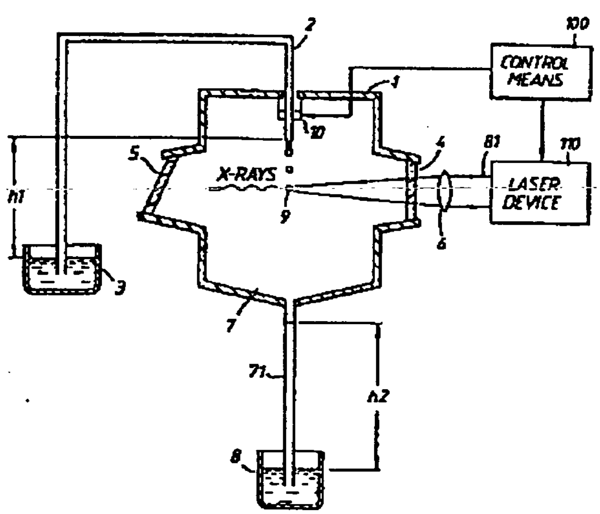

FIG. 1

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APPARATUS FOR PRODUCING SOFT X-RAYS USING A HIGH ENERGY BEAM

This invention relates to an apparatus for producing soft x-rays by impinging a high energy beam, such as a laser, or an electrically charged particle beam on to a target made of a liquid metal to produce plasma at high energy density and high temperature. More particularly, the invention relates to a plasma x-ray apparatus used in an x-ray exposure apparatus in a semiconductor manufacturing system.

As is generally known, soft x-rays are generated by plasma at high temperature and high density. Plasma having high temperature and high density can be instantly produced by impinging a high energy beam, such as a laser beam, upon the surface of a solid metal target. The x-rays produced from such plasma are characterised by (1) high brightness, (2) the x-ray beam has a nearly pin point source, (3) x-rays have a sharp pulse, and (4) if a YAG-laser which has a large duty cycle is used, the x-ray source can be used repeatedly.

Plasma x-ray apparatus has been used experimentally in submicron x-ray lithography and in measurement apparatus. In such experimental apparatus, a laser beam has been used to impinge on a target

formed by a solid metal surface. This experimental apparatus is disclosed in "Sov. Phys. Tech.", Phys., 28(7), p 863 (1983); "Submicron X-ray Lithography Using Laser-Produced Plasma As A Source", B. Yaakobt et al, Appl. Phys. Lett. 43(7), 1, pg, 686-688 (October 1983). However, if such experimental apparatus is used in a practical application, several disadvantages would result, namely, it would require regular replacement of the target material and the vacuum of the vessel must be broken when the target material is used up and has to be replaced.

In accordance with this invention there is provided apparatus for producing x-rays comprising a low pressure vessel having a window for the egress of x-rays generated therein; a target at an impact area in the vessel, said target serving to emit x-rays when impacted by a high energy beam and means for generating a high energy beam and directing the beam on to the target; characterised in that the means for generating the high energy beam is outside the vessel, the target is a liquid and means supply the liquid target to the impact area and control means are coupled to said beam generating means to control the energy beam so that the beam impacts the liquid target at the impact area.

In order that the invention may be more readily understood, it will now be described, by way of

example only, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic sectional view of apparatus for the production of x-rays according to an embodiment of the invention;

Figure 2 illustrates a modification of part of the vessel shown in Figure 1;

Figure 3 is a schematic diagram of control means for the x-ray apparatus shown in Figure 1;

Figure 4 is a schematic sectional view of a vessel forming part of the apparatus; and

Figure 5 is an alternative embodiment of the invention.

Figure 1 schematically shows an example of apparatus for producing soft x-rays according to the present invention. The apparatus comprises an evacuated vessel 1 having a fine tube 2 leading into the head portion thereof. A reservoir 3 contains mercury for use as a target and the end of the fine tube 2 extends into the reservoir. A window 4 on the side of the vessel wall permits a laser beam to enter into the vessel. There is an additional window 5 for the egress of x-rays. A control means 100 serves to control the timing of the mercury drops falling from the end of the fine tube and a laser device 110 projects a laser beam into the mercury drops 9 in the

vessel 1 through a lens 6 and the window 4. The mercury drops 9 are formed at the end of the fine tube 2 in the vessel by the action of surface tension and are caused to drop by vibration set up by a piezoelectric element 10 which is connected to the fine tube.

An amount q of mercury is as follows:

$$q = \frac{\pi}{128} \frac{1}{\eta} \frac{D^4}{l} (P_0 - \rho g h_1)$$

where,

h_1 = difference in height between the end of the fine tube 2 in the vessel and the surface level of mercury in the reservoir 3,

D = inner diameter of the fine tube 2,

l = length of the fine tube 2,

η = viscosity of mercury,

ρ = mass density of mercury,

P_0 = pressure on the mercury reservoir (usually atmospheric pressure).

When a mechanical vibration of frequency f (for example 1000Hz) is applied to the tube 2 by the piezoelectric element 10, the mercury drops out of the end of the fine tube with a timing of 1/f cycle in the form of discontinuous drops. The timing cycle of the discontinuous drops is synchronised to the laser pulse

timing (for example 100Hz). Then, it is impacted at 1/10 times each. At this time, the drop size d is as follows:-

$$d = \left(\frac{3}{64}\right)^{\frac{1}{3}} \cdot D^{\frac{4}{3}} \left(\frac{P_0 - \rho g h_1}{\ell \cdot \eta \cdot f}\right)^{\frac{1}{3}}$$

The drop size d decides to in focus point size of grade of the laser beam spot, for example, d is 0.5 mm ~ 2 mm. A stable range for producing the drops are selected with a size of the fine tube and a height h_1.

The height difference between the end of the fine tube 2 and the surface of the mercury in the reservoir 3 (h_1), the inner diameter of the fine tube 2 (D) and the length of the fine tube 2 (ℓ) are decided so that the drops do not flow continuously from the tube, which is related to the following equation:

$$\frac{D^5}{\ell^2}\left(P_0 - \rho g h_1\right)^2 \lesssim 4096\ \eta^2 \frac{\sigma}{\rho}$$

and, by the vibration, one drop is dropped into the vessel with each pulse of the vibration.

A reservoir 8 and fine tube 71 enable the target material to be collected, as shown in Figure 1, but, as shown in Figure 2, the target material may collect in the bottom of the vessel.

The piezoelectric element 10 is constructed

with a ceramic portion 16, electrodes 17, 18 and a brim portion 19 attaching the end of the fine tube 2 and the electrode 17. The element is operated by a driving source 21 outputting a sine wave 22. The electrode 18 is fixed to the wall of the vessel 1 with a stud 20. The signal 22 is shaped to a suitable pulse signal 28 for use with the laser device 110 through a wave form shaping circuit 23 shaping a signal 24, mono-multi vibrator 25 generating a signal 26 and a delay circuit 27. The signal 28 operates the laser device 110 in synchronism with the drops of mercury.

Figure 4 shows the invention applied to the lithography of a semiconductor body 30 mounted at a window 13 of the vessel which is sealed with a polyethylene thin film 15.

Figure 5 shows another embodiment of this invention in which a high speed electromagnetic valve 32 is used for displacing the mercury 3 by controlling compressed air 33 which is applied to the mercury reservoir 3 through a pipe 31. The timing of the valve 32 is synchronised to the laser pulse timing. The pressure ΔP is given by the following equation:

$$\frac{D^5}{\ell^2}(P_0 + \Delta P - \rho g h_1)^2 > 4096\, \eta^2 \frac{\sigma}{\rho}$$

The high energy beam may, for example, be an electron beam, a heavy ion beam, a light ion beam or a charge coupled particle beam.

The liquid material target may be one of the group consisting of indium, gallium, cesium or potassium at an elevated temperature, or a low melting point metal with a melting point less than 100^{C}.

A quantity of helium at low pressure may be present in the vessel 1.

Claims:

1. Apparatus for producing x-rays comprising a low pressure vessel (1) having a window (5) for the egress of x-rays generated therein;

a target (9) at an impact area in the vessel, said target serving to emit x-rays when impacted by a high energy beam and means (110, 6) for generating a high energy beam and directing the beam on to the target;

characterised in that the means (110) for generating the high energy beam is outside the vessel, the target is a liquid and means (10) supply the liquid target to the impact area and control means (100) are coupled to said beam generating means to control the energy beam so that the beam impacts the liquid target at the impact area.

2. Apparatus according to claim 1, characterised in that said target is formed by discontinuous drops of liquid.

3. Apparatus according to claim 1, characterised in that said target is of a metal with a melting point less than 100^{o}C.

4. Apparatus according to claim 3, characterised in that said target is mercury.

5. Apparatus according to claim 2, charactersied in that said target is one of the group comprising indium, gallium, cesium or potassium at an elevated temperature.

6. Apparatus according to any preceding claim, characterised in that said energy beam is a laser beam.

7. Apparatus according to any of the claims 1 to 5, characterised in that said energy beam is a high energy ion beam.

8. Apparatus according to any of the claims 1 to 5, characterised in that said energy beam is a high energy relativistic electron beam.

9. Apparatus according to any preceding claim, characterised in that said low pressure vessel contains helium under low pressure.

10. Apparatus according to claim 2, characterised in that said control means synchronises the arrival of the discontinuous drops of said liquid target and the high energy beam.

11. Apparatus according to claim 10, characterised in that said control means is further coupled to said target supply means to control the dispersion of the discontinuous drops of said liquid material target and to control the timing of the generation of the high energy beam.

12. Apparatus according to claim 11, characterised in that said control means comprises pulse drive means for generating pulses of the high energy beam and pulse delay means for delaying the pulses of the high energy beam to synchronise the pulses of the high energy beam with the discontinuous drops of said liquid material target.

13. Apparatus according to claim 13, characterised in that said control means further comprises vibration means coupled to said target supply means for vibrating said target supply means to disperse said discontinuous drops of said liquid target.

14. Apparatus according to any preceding claim, characterised in that there further comprises recovery means coupled to said low pressure vessel for recovering the liquid material forming said liquid material target after impact by the high energy beam.

15. Apparatus according to claim 14, characterised in that said recovery means comprises a fine tube attached near the bottom of said low pressure vessel and a reservoir connected to said fine tube for recovering the liquid material flowing through said fine tube.

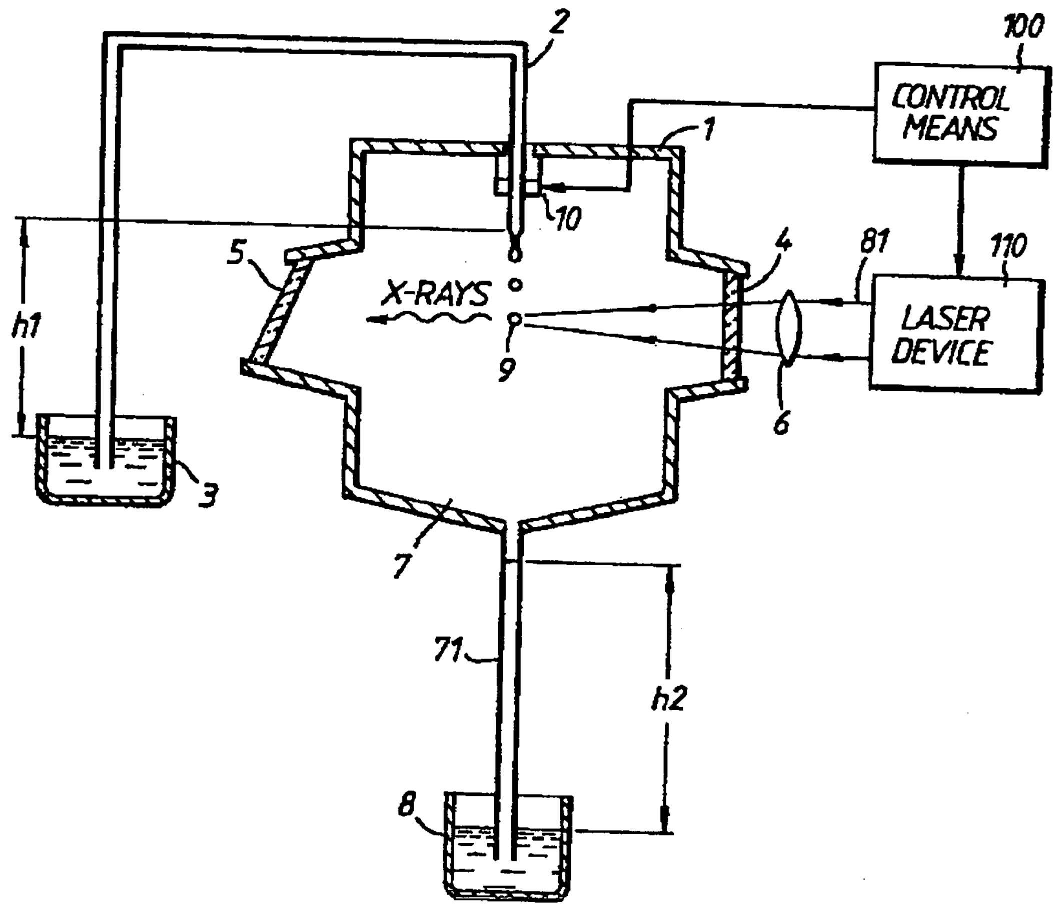
2
100
CONTROL MEANS
1
10
5
4
81
110
X-RAYS
LASER DEVICE
h1
9
6
3
7
71
h2
8

FIG. 1.

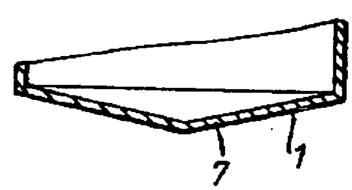
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FIG. 2.

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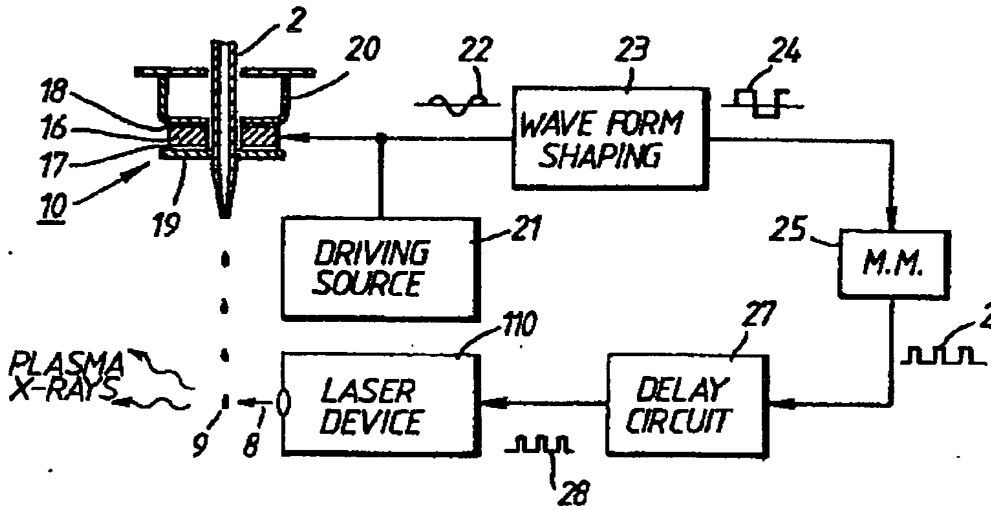

FIG. 3.

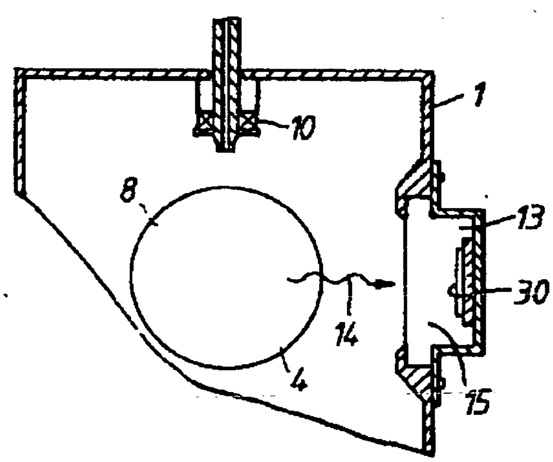

FIG. 4.

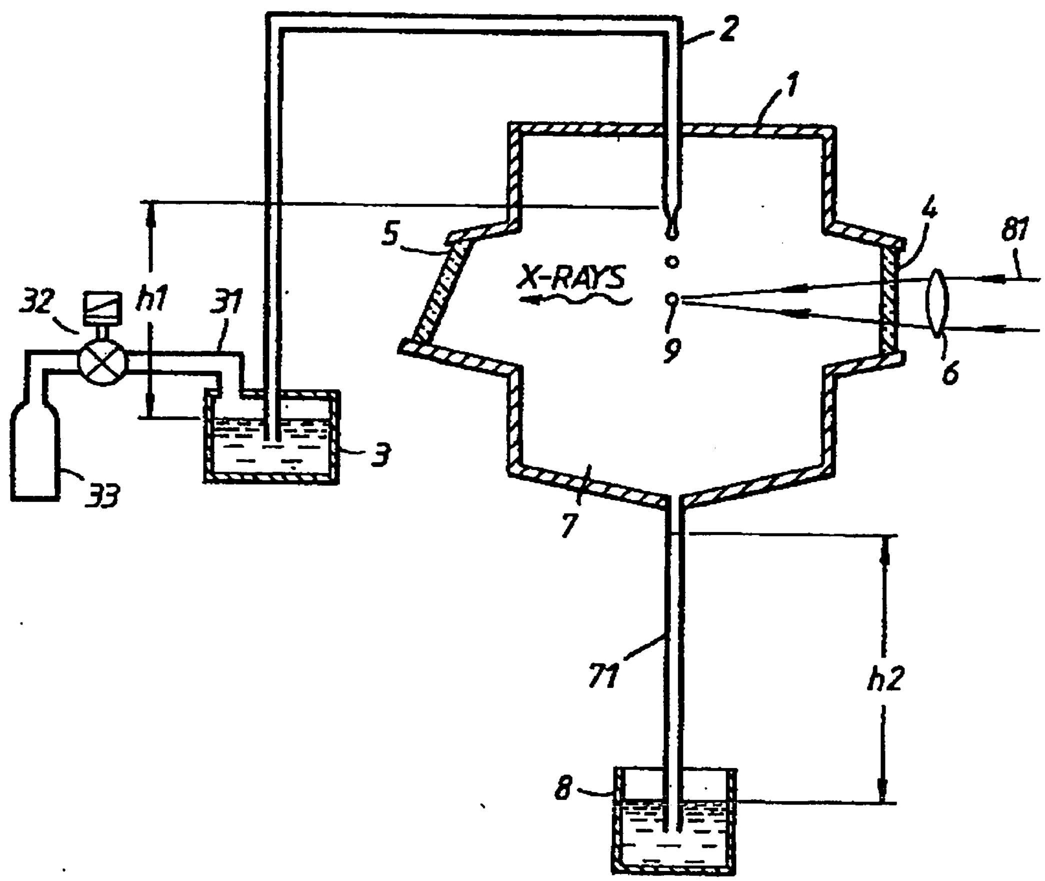

FIG. 5.